Draft CEC PIER-EA Discussion Paper

Energy and Climate Change

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Disclaimer

The purpose of this paper is to inform discussions among California Energy Commission (CEC) staff, other state agency staff, non-governmental representatives, representatives of academia and other stakeholders regarding the state of the research on climate change and energy in California. In particular, this discussion paper identifies gaps in our understanding and recommendations for future research initiatives with the end goal of supporting informed and systematic planning for climate change. Note that this paper is not intended as a research proposal and, therefore, does not include recommendations regarding specific research projects.

1.0 Description of Research Topic

About 90% of the gross greenhouse gas (GHG) emissions from in-state sources in California originate from the energy system, and more specifically from the combustion of fossil fuels. Power plants in California contribute about 12% of the total GHG emissions, but if we also consider CO_2 emissions from out-of-state power plants serving California, the contribution of this sector represents about 25% of the total emissions. According to state law, out-of-state emissions from power plants are counted in the official California inventory, but other sources of indirect emissions (e.g., production of fuel blending components in out-of-state refineries) are not. Emissions from the electric power sector, however, vary from year to year, not only due to expected growth in demand with increased population and economic activity, but also due to hydrologic conditions. Precipitation levels in California are highly variable from year to year. Dry years can result in increased annual emissions from power plants, which can be evident even in the overall total GHG emission inventory for California.

If we disaggregate CO_2 emissions from the combustion of fossil fuels by fuel type, natural gas and motor gasoline generate comparable GHG emissions. Given the relatively low carbon content of natural gas, this high contribution to total GHG emissions from natural gas is rather surprising at a first glance. However, this relatively high contribution is due to vast amounts of natural gas consumed in California to heat homes and buildings and to fuel power plants, which rely almost exclusively on this fuel.

Given the dominant contribution of power plants, the combustion of natural gas, and the energy sector in general to the overall GHG emissions in California, it is imperative to study how the energy sector can contribute to overall GHG reductions. As indicated in the sections below, both the demand for and generation of energy in California will be affected by climate change and, therefore, it is prudent to study these potential effects and the options available to cope with or adapt to climate change.

The overall policy questions that drive the preparation of this discussion paper are as follows:

- What are the potential impacts of climate change on energy generation and demand?
- What are the options available to the energy sector to cope or even thrive in a changing climate and a rapidly evolving worldwide energy market?
- How should the energy sector in California transform itself, taking into account the need for drastic GHG emissions reductions while minimizing overall negative economic impacts to rate payers and the economy of California in general?

2.0 Summary of PIER Program Research to Date on Energy and Climate Change

In this discussion paper, we focus on the activities of the Climate Change sub-program in PIER, which was created for the production of analytical studies on climate change. Other parts of the PIER program are supporting the development of new clean energy technologies and the tools needed for their successful implementation in California.

The PIER climate change sub-program started working in this area of research in 2001 supporting a study coordinated by the Electric Power Research Institute (EPRI) on the potential impacts of climate change in California. The final report released in 2003 included two highly relevant studies. The first study suggested that if a dry form of climate change (reduced precipitation levels) becomes a reality, the amount of electrical generation produced in our low-elevation hydroelectric power plants will be curtailed accordingly, and that electricity generation in the summer months—when it is most needed—would be severely reduced (Lund, 2003). The second paper suggested that net energy expenditures in California will increase because monetary expenditures for cooling will more than offset the reduced monetary expenditures for heating, but that the magnitude of the impacts could be mild to serious depending on the actual level of increased temperature experienced (Mendelshon, 2003).

Other PIER studies have enhanced the exploratory EPRI study. For example, PIER has explored how different potential manifestations of climate change would impact electricity generation in a high elevation hydroelectric system owned by the Sacramento Municipal Utility District (SMUD) (Vicuña, 2006) and high elevation hydroelectric units in California in general (Medellin, 2007). The California Value Integration Model (CALVIN), an engineering/economic model of the entire water system in California, has been upgraded to improve the representation of low elevation hydro units, which are mostly associated with large water reservoirs (Medellin, 2007). Under partial funding from PIER, researchers have also implemented the Water Evaluation and Planning (WEAP) model (a simulation model for water systems specially suited for climate change studies) for a part of the Sacramento Valley, including a representation of hydro units (Joyce, 2006). Both CALVIN and WEAP have been used to estimate the potential impact of climate change on electricity generation.

On the energy demand side, PIER has released two studies looking at the potential effect of climate change on the overall annual and peak electricity demand (Franco and Sanstad, 2007; 2008; Miller et al., 2007; 2008). PIER has also investigated the potential contribution of energy efficiency to lowering energy demand and contributing to GHG reductions (Rufo, 2007), and has started an exploratory study for past energy consumption trends in the residential sector. The flat energy consumption per capita observed in California has not been fully explained, and a clear understanding of the reasons for this trend is needed to develop successful energy policies.

Finally, for the issues related to the evolution of the electricity system, PIER has funded two exploratory studies. The first one, with researchers at UC Davis and Lawrence Livermore National Laboratory, was designed to investigate the effect of potential energy pathways in the energy transportation system on the electrical and natural gas systems. For example, a hydrogen pathway relying on natural gas for the production of hydrogen would have tremendous implications for natural gas availability, its prices, and electricity generation (Odgen et al., 2008). The second study was designed to explore the feasibility of creating an energy model for California embedded into a national and global model to study the potential evolution of the California's energy system in the context of a national and worldwide energy market. Researchers at Pacific Northwest National Laboratory (PNNL) successfully created a preliminary version of such a model with the ability to simulate parts of the residential sector and with some preliminary representation of the options for renewable sources of energy in California (Smith, 2007).

3.0 PIER Accomplishments

As it may be evident from the above discussion, PIER has strived to achieve the overall goals identified in the 2003 PIER Climate Change Research Plan, but much more is still needed. The U.S. Climate Change Science Program (CCSP) states the following in its assessment report, entitled "Effects of Climate Change on Energy Production and Use in the United States" (CCSP, 2007):

> *California is unique in the United States as a state that has examined possible effects of climate change on its energy production and use in some detail... Led by the California Energy Commission and supported by such nearby partners as the Electric Power Research Institute, the University of California–Berkeley, and the Scripps Institution of Oceanography, the state is developing a knowledge base on this subject that could be a model for other states and regions (as well as the nation as a whole).*

While research supported by PIER and others has allowed us to make significant progress in our understanding of how climate change may affect the energy system, it is not clear how this understanding is being used by natural gas and electric utilities, or in the development of energy policies (e.g., the development of energy efficiency standards considering a warming climate). At the same time, there is some evidence that some utilities are beginning to think about how climate change may affect the operation of their systems (Freeman, 2008).

4.0 Non-PIER Accomplishments in this Area and Opportunities for Collaboration

As indicated in the section above, the U.S. Climate Change Science Program (CCSP) has produced a comprehensive review of the literature on climate change and energy. This assessment is an invaluable tool for informing the national research agenda and the agendas for regional and state efforts. This discussion paper relies heavily on this USCCSP report.

Different research groups around the world have developed sophisticated energy-economic models to study the potential evolution of national and international energy systems with a long-term perspective. Some of these studies have been used to inform the development of energy research strategies, while others have tried to understand the differences in models that affect their relevance in informing energy and climate change policy.

The Western Governors Association has also commissioned a study on the potential impact of climate change on energy production in the West. It is plausible that other similar studies for other states may have escaped our attention.

5.0 Research Underway/Committed to via PIER Process

PIER is focusing its efforts on three areas of research related to energy: (1) hydropower production and water-related studies; (2) adaptation; and (3) understanding how the energy system in California has evolved and how it should change in the future. Each of these areas is described further below.

Hydropower production and water-related studies

Work continues with the CALVIN and WEAP models. For example, researchers at UC Davis are enhancing the CALVIN model to track the energy implications of different potential adaptation options for the water sector due to the fact that about 19% percent of the energy consumed in California goes for the transport, treatment, and pumping of water (Klein, 2005) and, therefore, different water systems can have very different energy implications. In addition, some adaptation options in the water sector (e.g., widespread desalination or more pumping of water to and from groundwater aquifers) may substantially increase energy demand in California.

Researchers at UC Berkeley and Lawrence Berkeley National Laboratory (LBNL) are improving their engineering model representing the high-elevation hydro system owned by SMUD, and are extending their analysis to a high-elevation system owned by Southern California Edison. They are also using confidential residential water and energy consumption household data to develop the econometric relationships needed for a joint estimation of changes of water and energy demand with weather. Future enhancements include the use of these equations with an urban expansion model to estimate future water and energy consumptions in a geographical information system (GIS) framework.

Adaptation

A study funded by the National Oceanic and Atmospheric Administration (NOAA) resulted in two papers suggesting that probabilistic forecasts and a modern decision support system could substantially improve the operating efficiency of the Shasta reservoir, a major water reservoir in Northern California, and that the same management system could also reduce the negative impacts of climate change (Yao, 2001). This theoretical study was followed up by a demonstration project funded by NOAA, CALFED Bay-Delta Program (CALFED), and PIER, designed to develop a similar system for the integrated management of five major multipurpose reservoirs in Northern California, which includes Shasta (Georgakakos, 2005). The research team headed by the Hydrologic Research Center (HRC) developed the Integrated Forecast and Reservoir Management (INFORM) system over a period of three years. HRC and water managers tested the system on a near-real time basis with INFORM, suggesting different management options while the water managers continued to use their current operating rules. A posteriori evaluation of the performance of the INFORM system clearly demonstrated that INFORM was superior to the existing operating rules, at least for the demonstration year. Agencies in charge of the operation of these reservoirs are now seriously considering using INFORM for reservoir re-operation. This is a good example of the benefits of developing tools and methods to adapt to current climate variability as a means to adapt to future climate change and increased climate variability.

Evolution of the energy system

In-depth econometric studies are underway at UC Berkeley and LBNL on energy demand and climate change. Some of these studies make use of confidential household water and energy demand data to determine the climatic and non-climatic factors affecting water and energy demand. A UC Berkeley-led effort is investigating the most likely reason for the observed flat trend in electricity consumption per capita in California in the last 30 years using energy consumption data from California and other states. This is an extremely important topic of research because the state needs to know, with a higher level of confidence, the likely effect of existing and future energy efficiency programs on energy demand.

Researchers at LBNL, in collaboration with other groups, are studying the potential penetration of ambitious energy efficiency options in the residential, commercial, and industrial sectors from a medium-term (2025) and long-term (2050) perspective. Also, PIER has recently released a request for proposals to replicate and enhance the study done by Pacala and Socolow (2004) for California, focusing not only on existing technological options but also on newly emerging technologies. Researchers at PNNL are expanding their California model to include a representation of all the major energy carriers and all the energy sectors. The final goal is to explore potential energy pathways for California, and to conduct an analysis of energy research portfolios similar to the work being done using the MARKet ALlocation (MARKAL) model for the Global Climate & Energy Project at Stanford University (Sweeney, 2008).

6.0 Gaps in Research/Knowledge Relevant to California

Since the 2003 PIER Climate Change Research Plan, new developments have emerged that require a change in the energy research priorities for California. First, with the passage of the California Global Warming Solutions Act of 2006, attention has begun to shift from theory to actual implementation of GHG emissions reduction strategies. The draft Scoping Plan released by the Air Resources Board (ARB) suggests that the electricity sector would contribute about 28% of the needed GHG emission reductions required to bring the projected 2020 emissions to 1990 levels (ARB, 2008).[1] Second, the

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[1] In practice, since the Scoping Plan is proposing to include the electricity sector in the cap-and-trade program. This sector, in addition, will have to contribute to the 35.2 million metric tons of carbon dioxide equivalent ($MMTCO_2E$) needed to bring estimated overall California 2020 emissions to 1990 levels. The 35.2 $MMTCO_2E$ represents 21% of the total reductions required by 2020.

research community (e.g., the CCSP's Synthesis and Assessment Product 4.5 [SAP 4.5]) has suggested that the energy production and use sector is impacted by climate change (CCSP, 2007)). Third, the physical impacts of climate change are emerging more rapidly than expected, and global greenhouse gas emissions are increasing at a faster rate than have been assumed in any current climate change scenarios (Raupack, 2007). Because of these developments, analysts and policymakers are beginning to take seriously the prospects of more severe climate change by the latter part of this century.

Given these significant changes, it can be suggested that the most serious gaps in knowledge relevant to California's energy systems are understanding: (1) how best to minimize the impacts on rate payers of transforming the electricity and natural gas systems; and (2) what climate change means in terms of impacts on energy production and use in California. SAP 4.5 and other sources, including the CCSP's "United Synthesis Product," due out in late 2008, suggest several needs for expanding the knowledge base to respond to projected conditions in California. The gaps can be discussed in three categories: energy use, energy production, and indirect effects—each of which is described further below.

Energy use

Current gaps in knowledge include effects of both gradual changes and the prevalence of extreme weather events due to climate change, particularly alternatives for adaptation to reduce social and economic effects:

- Effects on population, economic sectors, and energy distribution systems of more frequent heat waves, equivalent to or worse than the heat wave of summer 2006, including emergency preparedness plans.
- Potentials to increase efficiency improvements in space cooling in order to extend affordable air-conditioning to a larger share of California's population.

Energy production

Current gaps are extensive, emphasizing impacts of climate change on energy production and supply, and also potentials for risk management through adaptation:

- Possible risk management strategies for adding resilience to energy supply systems that may be subject to stress under possible scenarios for climate change, including relatively severe climate change.
- Effects of and adaptation alternatives to reduced water supply for hydroelectric power generation and other consumptive uses of water by the electricity sector (including bioenergy production as appropriate).
- Potentials for transformational energy and energy-related technological development to ease stresses associated with climate change (such as affordable seawater desalination).
- Integrated studies of the energy system to inform the development of energy research portfolios.

Indirect effects

California also needs to consider what impacts of relatively significant global climate change on its energy systems might mean for its economy, both positively and negatively:

- Implications of changing regional patterns of energy use in the United States for California's energy supply institutions and customers, including positive or negative implications for California's economic growth.
- Implications for California of climate change policy interventions associated with cap-and-trade regulations on greenhouse gas emissions, including possible energy price increases.
- Possible opportunities for California to create economic opportunities by pioneering technologies for adapting to climate change.
- Identification of low-cost offsets that utilities could use to lower the compliance costs with future mandatory GHG emissions reduction, which will be in effect in 2012.

Given time and space limitations for the preparation of this discussion paper, we will expand upon only two of the research gaps listed above under "energy production": (1) possible risk management strategies for adding resilience to energy supply systems; and (2) integrated studies of the energy system to inform the development of energy research portfolios.

Possible risk management strategies for adding resilience to energy supply systems

Climate change will impinge on energy infrastructures both inside and outside of California. For example, if hurricane activity increases in the Atlantic, as predicted by some climatologists, natural gas and petroleum products from the Gulf Coast could be severely impacted multiple times in the future. Below are some of the issues that should be studied:

- The 2006 heat wave was one of the greatest heat waves in California in the last 60 years—in terms of duration, intensity, and geographical coverage (Gershunov, 2008). Even though it would be impossible to irrefutably link this heat wave to climate change, the characteristics of the 2006 heat wave resembled weather patterns and behaviors expected from climate change, including relatively hot nights (Gershunov, 2008). Detailed analysis of the historical record with careful modeling analysis to estimate future conditions should be conducted to estimate the likelihood of similar events in the near future (10 to 20 years). Unfortunately, exclusive reliance on downscaling of the outputs of global climate models may not be sufficient because the current versions of global climate models may not adequately simulate extreme events. In addition, empirical seasonal forecasts such as the ones developed by Scripps Institution of Oceanography (Scripps) for PIER (Alfaro, 2005) should be improved to see if it is possible to estimate the likelihood of hot summer conditions, using as the main driver sea-surface temperatures in the Pacific Ocean four to six months before summer. In addition, short term forecasts of important features—such as the Delta breeze, which plays an important role in energy demand in the Central Valley—could be improved using empirical, numerical, or weather forecast models. The lack of transport of relatively cool air from the San Francisco Bay Area to the Central Valley results in high afternoon temperatures in the valley and increased cooling demand. Scripps has shown that it is possible to improve the forecast a day or hours ahead of this atmospheric-topographic feature (Pierce and Barnett, [Year to be provided]).

- The 2006 heat wave provided excellent insight into which preventive measures might be developed and implemented to avoid outages in the California energy system during future heat waves. During the 2006 heat wave, there were outages mostly due to transformer failures. Should the replacement period for these transformers be changed or should new standards be developed to reduce their failure rate during similar or even more intense heat events? Is the capacity of transmission lines seriously affected by high temperatures? If this is the case, what can be done?
- High temperatures reduce the thermal efficiency of power plants, thereby reducing potential generation. Will this be a serious problem in California? What are the economic implications?
- The Sacramento/San Joaquin Delta region is home to important energy infrastructure, such as underground natural gas storage systems and transmission lines (Lund, 2007). Sea-level rise and increased runoff during the winter and early spring seasons will increase the risk for the catastrophic failure of the levee system protecting the Delta. What are the implications, if any, of this scenario to the natural gas and electricity system in California?
- Coastal power plants may be affected by sea-level rise and the potential increase in storminess. What can we learn from prior severe weather events, such as the 1982 El Niño coastal flooding situation? The hourly sea level rise scenarios developed by Scripps could be used to inform these analyses and a prior study prepared for the Energy Commission could be an excellent starting point.
- Increased runoff could also damage water reservoirs and their associated hydroelectric generation systems in California. What is the potential severity of these damages? What preventive measures could be implemented?

Integrated studies of the energy system to inform the development of energy research portfolios[2]

Different research institutions have developed engineering-economic models—such as MARKAL, Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), and the Mini Climate Change Assessment Model (MiniCAM)—which have been used to estimate how the energy system should evolve under different assumptions about carbon emission limitations. However, these models can be substantially improved for regional studies, including addressing the following issues:

[2] This discussion is mostly based on a presentation given by Guido Franco at the *Workshop on Future Priorities for the U.S. Climate Change Science Program*, organized by the National Academy of Science in Washington, DC (October 15–17, 2007).

- Most of the models assume that climate conditions are the same under the different emissions scenarios. This obviously is not the case, as shown in the figure below. This model limitation, which is common in all the models used to develop the scenarios in the *Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios* (IPCC SRES), would underestimate the energy costs associated with higher emission scenarios and may de-emphasize the reduced demand (at least for cooling) under the low emission scenarios (e.g., B1). A recent version of MiniCAM will address this limitation using energy demand relationships that are a function of ambient air temperatures.

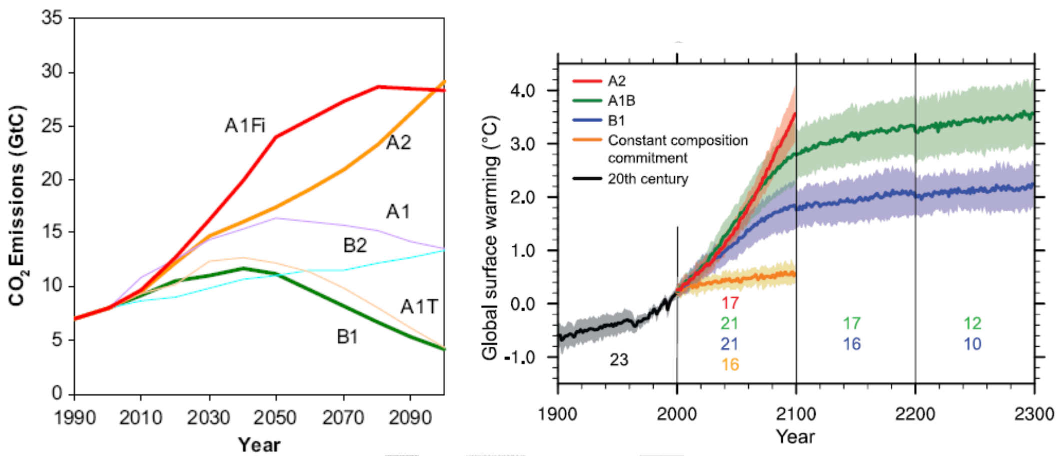

Figure 6-1. Projected carbon dioxide emissions under different IPCC global emission scenarios and potential global average temperature responses. (IPCC, [year])

- Some models assume that the same suite of energy technologies is available at the same time for all the potential emission scenarios (e.g., A2, B1)—an assumption that will tend to overstate the costs of low energy pathways. For example, low cost photovoltaic systems should be available much sooner in the B1 than in the A2 scenario, given the push that a move to a low carbon economy that the B1 scenario assumes will be created. Economies of scale would also dictate the same clean technologies eventually should be less costly (expressed in cents per kilowatt-hours for electricity-generating technologies), given the higher penetration of photovoltaic units in the low emission scenarios.

- The use of econometric relationships developed using historical data is questionable when dealing with climate change, at least for emission pathways associated with very low carbon emissions. There is no historical precedent for the rapid transformation of the energy system that will be needed to address climate change and, therefore, using past behavior to infer future behavior should be done cautiously. At the very least, a careful examination of the situations is necessary when the econometric relationships are being used outside their calibration range. These types of inferences are especially problematic for computable general equilibrium models because their stylized representation of the economy and the energy system is strongly inferred on past behavior.

- Practically all of the energy-economic models used for climate change studies are based on neoclassical growth models in which growth is a process of accumulation of capital and resources, and technical progress is mostly exogeneous (Agnion, 1999).

Modern economics frameworks, such as endogenous growth theory, should be used to consider factors such as education, research, market structures, income distribution, and sustainable development. According to Aghion and Howitt (1999):

> *The excitement of endogenous growth theory is that it provides the tools to handle endogenous technological change and innovation within a dynamic general equilibrium setting. This allows us to develop tractable and flexible models that embody the vision of economic life as an endless succession of innovation and change wrought by competition. With these tools we can bring to bear all that we have learned in economics about incentives, organizations, and institutions, not only on the problem of economic growth per se but also on the many other economic phenomena that interact with growth.*

- Models should start considering the cost of adaptation to economic growth. All of the IPCC SRES models do not take into account these costs, resulting in a potential underestimation of the costs associated with low carbon pathways. High GHG emission scenarios may, in fact, result in lower income per capita and/or economic growth given the fact that some funds would be allocated to relatively unproductive activities, such as building levees and forest fire protection. Some simple models, such as the Dynamic Integrated Model of Climate and the Economy (DICE), take adaptation costs into consideration, but there are reasons to believe that the estimated damages and adaptation costs are unreasonably low (Hanemann, 2008).
- Virtually all of the engineering-economic models in the technical literature assume that the economic impacts of purchasing local offsets is the same as purchasing offsets outside the modeling region. This assumption seems highly problematic because the generation of local offsets may result in job creation (e.g., planting trees) at the local level and an internal transfer of funds (e.g., electric utilities buying credits from growers served, perhaps, by the same utility or in the same state) while the purchase of offsets overseas (e.g., from Mexico or China, in the case of California) does not result in a recirculation of funds in the local economy. In addition, all of the co-benefits of local offsets (e.g., increased agricultural production with greater levels of soil carbon, reduced emissions of conventional air pollutants) are not realized at the local level.

7.0 Conclusions and Prioritized Recommendations

Several California-specific studies have been conducted in this area of research. However, this discussion paper suggests that more work still is needed and should be supported. In general, the authors recommend the following topics as priority:

- Possible risk management strategies for adding resilience to energy supply systems that may be subject to stress under possible scenarios for climate change, including relatively severe climate change.
- Effects on population, economic sectors, and energy distribution systems of more frequent heat waves, equivalent to or worse than the heat wave of summer 2006, including emergency preparedness plans.
- Implications for California of climate change policy interventions, associated with cap-and-trade regulations on greenhouse gas emissions, including possible energy price increases.

- Effects of adaptation alternatives to reduced water supply for hydroelectric power generation and other consumptive uses of water by the electricity sector (including bioenergy production, as appropriate) and, in general, the evolution of the energy system under a carbon constrained world.

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